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A simplified transport model for the ex-ante evaluation of road pricing on a project basis

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Abstract (183 words)

The objective of this research is the development of a diversion transport model that adopts a specific technique for forecasting changes in demand when examining road pricing schemes for two generic types of road projects: a new road project and the upgrade of an existing roadway. It is assumed that the key drivers of demand are roadway capacity and generalized cost of travel. The model incorporates most of the transport behaviour and sensitivity desired in a transport model, yet it has a simple structure (sketch-based model) and manageable data requirements. Due to its simple structure the model is developed for use mainly by public authorities, with limited resources or know-how in transport modelling. The model was applied in order to produce a (defensible) simulation of "immediate" impacts of road pricing policies (traffic volume, amount of travel, journey time, speed etc.) on given road projects. Model results were used for the estimation of traffic-related impacts that are usually included in an ex-ante evaluation of a road project (reduction of traffic congestion, improvement of safety level, improvement of air quality and reduction of noise annoyance).

Keywords

Road pricing; transport modelling; policy making; ex-ante evaluation.

Introduction

Despite EU's encouragement towards member states to include road pricing in their political agenda, one of the basic challenges in all governmental levels, is to seek a "balanced way" to do that. Such a way implies the development of a coherent modelling framework to support the assessment of road pricing policy options against -often conflicting- policy objectives. Such an assessment is by default a difficult task; especially in the early stages of a project and/or policy development where alternative options are still "ideas" and should be quickly "scanned" and interpreted as either promising or not suitable for further development. The task is more difficult in the case of a public authority (of local/regional level) with limited resources or know-how in policy modeling.

Key consideration when developing a transport model to support the ex-ante evaluation of alternative policy options is that model's set-up, takes place within the overall evaluation process (Boulter and Wignall, 2008; Department for Transport, 2009; Furnish and Wignall, 2009; PROSPECTS, 2003).

In the framework of Consensus project, a transport model has been developed, tailor-made for the evaluation of the Consensus transport policy scenario, which concerned "*support of public authorities, relevant to the development, planning and management of roads, to comparatively evaluate and identify most optimal road pricing schemes -for further assessment- either for a new road infrastructure project or for the upgrade of an existing one, against a range of policy objectives that cover the main pillars of sustainability*" (CONSENSUS, 2014).

To our knowledge, there have been only few attempts to formulate simple and comprehensive planning tools. The aim of this study is to address these two linked issues. The remaining part of this paper is organised as follows: Section 2 presents the policy and assessment context of Consensus project. This is followed by a review of transport modelling techniques in Section 3. The development of the Consensus transport model is described in Section 4. The final section concludes with major findings, and discusses model's limitations.

2. Policy and Assessment Context of Consensus

Two main goals are identified by transport economists behind road pricing (Pigou, 1920; VTPI, 2013) and adopted nowadays by the EU: funding of Europe's vital road infrastructure and sustainable use of road transport infrastructures currently affected by congestion and consequent problems (CEDR, 2009; PIARC, 2008).

Road pricing policy options examined in Consensus are basically (different) combinations of the following components:

i. Project type; new project or upgrade of an existing one.
ii. Project scale: corridor (main axis), facility (corridor's part with specific operational or geographical characteristics) or spot (bridge/tunnel) further differentiated by length and typical cross-section
iii. Application area: urban or interurban. Urban area is further differentiated by population size (small if population < 2.000.000, large if population > 2.000.000)
iv. Operational Authority: public or private entity
v. Road pricing types: Road tolls (fixed rate), Distance-based charging, Congestion charging
vi. Toll collection technique: Pass, Toll booths, Electronic Toll Collection (ETC) with transponders or smart cards, Optical Vehicle Recognition System (OVR), GPS (or GNSS) based pricing and various combinations of these techniques.
vii. Price level (base fee – concerning passenger cars) and structure (differentiations per vehicle, per day period and discounts for frequent users).

Since Consensus transport policy scenario aimed to assess policy options for a specific/given project -and not examine alternative project options-, for any alternative under assessment the upper half of the components list (i) to (iii) are considered fixed and the optimal road pricing policy option is produced by searching optimal (combinations of) parameters in the bottom half of the components list (iv) to (vii).

Policy objectives adopted in Consensus transport policy scenario were developed around four main sustainability dimensions, namely Economy, Mobility, Environment and Society (Schwaab and Thielman, 2011; Valentin and Spangenberg, 2000; UNDPCSD, 1996), including: economic feasibility, financial viability, impacts on traffic congestion, safety impacts, environmental impacts (air quality, noise) and users' convenience.

Policy objectives might reflect general goals and desired outcomes of a road pricing policy but they do not specify performance targets. To this end, based on relevant literature and research review (CONSENSUS, 2014), appropriate indicators (and metrics), presented in Table 1, were chosen to measure policy options' overall performance.

Table 1. Objectives and metrics for road pricing schemes evaluation

Objectives	**Indicator**	**Metrics**
RP economic feasibility	Relative investment cost	Qualitative; Verbal Scale *Indicating how expensive is the installation and/or purchase of Equipment for each toll-collection technology.*
RP financial viability	Relative Operational Cost	Quantitative; % of gross revenues dedicated to cover toll collection costs, including administration, enforcement and consumables *Related to toll-collection technique and operational authority structure*
Reduce traffic congestion	Increase in Level of Service	Quantitative; decrease of ratio Traffic Flow/Capacity *Related to speed, traffic volumes and/or vehicle kilometres travelled*
Improve safety	Reduction of accidents costs	Quantitative; % decrease of accident costs *Related to vehicle kilometres travelled*
Improve air quality	Reduction of air pollution external costs	Quantitative; % decrease of air pollution external costs *Related to vehicle kilometres travelled*
Reduce noise annoyance	Reduction of noise external costs	Quantitative; % decrease of noise external costs *Related to vehicle kilometres travelled*
Ensure user convenience	User convenience level in using the RP system	Qualitative; Verbal Scale *Indicating how convenient is for a user to pay charges using each toll collection technique.*

In this framework, there was clearly a need of a simple –yet not simplistic- transport model, with manageable data requirements, for estimating the main effects of road pricing policy options for a typical road project. Main effects include the "immediate" (first-order) impacts of road pricing i.e. impacts on travel costs and road network's functionality (traffic volume, amount of travel, journey time, speed etc.) (CEDR, 2009; Bowerman, 2007; Eliasson, 2008; Downs, 2007).

Then the estimation of "chain" (second-order) impacts, such as reduction of the external costs of accidents, air pollution and noise, could be estimated relatively straightforward (Danna et al., 2012; Elvik & Vaa, 2004; Eenink et al., 2007; CE Delft et al., 2008). Estimation of the rest of the objectives was not based on the transport model but on analysis of readily available domain data and expert judgement.

3. Review of transport modelling techniques

3.1 Modelling Techniques in Transport Sector

Transport models are predominantly used to predict transport demand under specific conditions' changes (i.e. infrastructure provision, management measures implementation, pricing instruments enforcement). Two main model types are commonly used:

- Conventional, four-step transport models; the most well-known and used in practice.
- Simplified models; usually applied to make rapid progress in particular circumstances.

Unlike conventional models, which tend to be complex, time and data consuming (Furnish and Wignall, 2009; TDM, 2014) and more dedicated in analyzing "operational characteristics" (Hensher and Button, 2007), simplified models represent the transport system with a high degree of network and zonal aggregation and produce mainly "indicative" or "approximate" forecasts, Three main types of simplified models exist (Furnish and Wignall, 2009; Khisty and Sriraj, 1996; Matas and Raymond, 2003; Zahavi, 1981):

- Simplified demand models: Mode choice models, Elasticity based models
- Structural models: Generalized relationship models, Regression based models.
- Sketch planning models

3.2 Modelling Practices for Estimating the Impacts of Road Pricing

Currently, there is no standard approach for representing tolls in travel demand models (Spear, 2005; Vovsha et al., 2005) and there is no consensus as to the best methods for developing traffic forecasts when examining road pricing implementation (Kriger, 2005). A review of current practices for road pricing applications identified sketch planning methods among modelling procedures (Smith et al, 2004; Spear, 2005; Urban Analytics Inc. and URS Corporation, 2004) as the most quick-response tools for project evaluation. These are often spreadsheet-based techniques that apply similar to conventional models concepts to aggregated or generalized data. Because of their flexibility, these tools are often developed by Authorities' staff or consultants for a specific project.

3.3 Modelling Assumptions and Data Requirements in Road Pricing Analyses

Regardless of the modelling procedure used, a common underlying assumption exists; travellers choose among a set of alternatives and select those having the lowest generalized cost (Spear, 2005). The generalised cost is equivalent to the price of the good in supply and demand theory, and so demand for journeys can be related to the generalised cost of those journeys using the price elasticity of demand. Supply is equivalent to capacity (and, for roads, road quality) of the network.

In economic theory, it is well established that there is an inverse relationship between demand and cost (Hyman and Wilson, 1968; Lesley, 2009). As such, changes in generalised cost of travel cause inverse changes in demand for travel and this latter mentioned change is calculated using the respective elasticity. Since most benefits/costs from interventions/changes in transport system result from generalized cost changes (Van Wee, 2011), transport models basing demand forecasts on generalized cost changes can provide relatively straightforward quantitative estimations of dominant benefit/cost categories i.e. safety impacts, environmental impacts etc.

4. Development of Consensus transport model

For the development of the Consensus model an ordered process of five development stages –before application - was followed.

- Perceptual stage: a general understanding of road pricing impacts on travel costs and road network’s functionality (traffic volume, amount of travel, journey time, speed etc.).

- Conceptual stage: perceptual process described by equations based on transport literature and practice,
- Computing stage: transferring of the conceptual process to computer code.
- Calibration stage: adjusting various model parameters to better represent real conditions.
- Validation Stage: comparing modelled results against observed data; in reality, process of validating and calibrating a transport model is an iterative process.

4.1 Perceptual Stage

Since road pricing has an impact on travel behavior and freight patterns, it affects the functionality of transport links. Pricing can affect volume, distance travelled, timing of travel as well as modal split or route choice on local networks (Bowerman, 2007). Functionality improvements take place if congestion or stop-and-go traffic during peak hours is reduced. As traffic flow improves, travel times and vehicle operating costs reduce, thereby outweighing the cost impact of charges (CEDR, 2009). Also, travel times become more predictable and travel planning is easier, causing in turn further time savings as travelers have fewer needs to budget additional time to avoid late arrival (Danna et al., 2012).

4.2 Conceptual Stage

The basic equations of this stage include:

- Demand drivers' estimation; mainly generalised cost (incl. travel time cost and vehicle operating costs),
- Demand changes estimation; as function of specific drivers/factors affecting it (generalised cost and roadway capacity) as well as respective elasticities of demand.

4.2.1 Demand drivers

The development of an analytical model to estimate the likely 'capture' (in percentage terms') of in-scope traffic by toll roads requires conversion of all costs and benefits in the same units. In particular, time and money needed to be converted to the same currency often termed "generalized cost". As part of this process, a "Value of Time" (VoT) is calculated for all the key behavioural segments in the model.

An improvement in supply conditions due to for example an improvement in the corridor capacity leads to a reduction in equilibrium generalized cost. To define generalized cost; generalized cost is an amount of money representing the overall disutility (or inconvenience) of travelling between a particular origin (i) and destination (j) by a particular mode (m) (Vovsha et al., 2005). In principle, this incorporates all aspects of disutility including the time given up, money expenditure and other aspects of inconvenience, but in practice the last of these is usually disregarded. For travel between (i) and (j) user's benefit is estimated by Equation 1:

$$UserBenefit_{ij} = ConsumerSurplus_{ij}^{I} - ConsumerSurplus_{ij}^{0}$$

1.

Where 'i' indicates the do-something scenario (the proposed project) and '0' the do-nothing (the base case). A useful approach in explaining travel choices is to relate demand to a generalized cost which incorporates various important elements.

Generalized cost function should be considered as a linear function of its component variables. More specifically travelers' generalized cost (Equation 2) is a linear additive function of Level-of-Service (trip length, time) and price components (direct monetary costs such as tolls) related to the perceived disutility of travel. The components of the journey are weighted by parameters which are compiled (e.g. km-costs), or perceived by the traveller (e.g. value of time). Generalized costs are differentiated by vehicle type (passenger cars, trucks) - and trip purposes (commuting, all other) for the variable of 'value of time'-.

$$c_{ij}^{m,tp,ut} = \alpha_1 * \mathrm{T}_{ij} + \alpha_2 * D_{ij} + Toll$$

2.

$c_{ij}^{m,tp,ut}$: generalised cost of travelling from zone (i) to zone (j), by vehicle type (m) for trip purpose (tp) and for user type (ut)

α_1 : value of time, for vehicle type (m) and trip purpose (tp)

T_{ij} : travel time from zone (i) to zone (j)

α_2 : vehicle operating cost for vehicle type (m)

D_{ij} : distance from zone (i) to zone (j).

$Toll$: toll encountered by a trip from zone (i) to zone (j), for vehicle type (m) and for the specific user type (ut)

m : vehicle type, m= passenger car, truck

tp : trip purpose, tp = commuting, other

ut : user type, ut= frequent (discount), random

Values of time for passenger car users are usually estimated based on Stated Preference (SP) surveys. For Consensus Project (CONSENSUS, 2015) VoT values per country and per trip category are taken from the HEATCO study (2006), as this is considered one of the most complete, recent and officially suggested by the EC.

Vehicle operating cost (VOC) is heavily dependent on road geometry and road operational characteristics, travel speed and pavement condition. VOC include costs for fuel, maintenance, tyre replacement, depreciation, tax and insurance. To derive VOC the methodology proposed by Poriotis and Vakirtzidis, 2001 was used, where VOC is calculated as a function of the average travel speed for each vehicle type, using Equation 3:

$$VOC^m = a*V^2 + b*V + c$$

3.

VOC^m : vehicle operating cost, for vehicle type (m)

V : vehicle’s speed (in km/hour)

a,b,c : parameters dependent on vehicle's technical characteristics:

Parameters	Passenger Cars	Trucks
a	0,00002914	0,000135
b	-0,00502432	-0,017436
c	0,4256765	1,426324

4.2.2 Forecasting demand changes

Consensus model adopts diversion models' technique, as such does not account for "induced traffic". It only accounts for generated traffic.

However, usually existing land use constrains such behavioural changes; on most trunk road schemes induced traffic impacts resulting from such changes are likely to appear progressively and be limited to the long term (<10 years). Furthermore, in most cases, although new schemes are expected to create significant reduction in travel time, the timesaving benefits will be outweighed by the higher tolls; consequently, induced traffic will be limited.

The key assumption of Consensus transport model, when forecasting demand, is that demand (Y) changes, due to roadway improvements and/or conditions changing, are estimated based on changes of two main demand drivers: capacity (CP) and generalized cost (c) (Equation 4).

$$\mathrm{Y} = f(c, CP)$$

4.

Key piece of information needed for travel forecasting, in the absence of a 4-stage traffic model, are elasticities. The elasticities provided in this project are the outcome of a very wide literature review and cover various studies from different geographical locations (CONSENSUS, 2015).

Consensus model uses travel demand elasticities (measured in vehicle-kilometers travelled) with respect to capacity and generalized cost, to estimate new travel that may be generated over and above traffic that is simply rerouted from other highways. This includes new trips generated or attracted to new development, and existing trips diverted from other destinations.

An elasticity of demand with respect to capacity of 0.2 and an elasticity of demand with respect to generalized cost of -0.31 were assumed. These values were the average of the range of (each) demand elasticity, found in the literature referenced above. The approach taken to determine changes in demand levels due to changes in capacity and generalized cost is based on the PDFH approach (Arup and Oxera, 2010).

According to Arup and Oxera study (2010), in order to estimate/forecast the level of new demand, an index of the ratio of new demand to previous demand is calculated. The index is then applied to an existing demand level to determine the forecasted value of new demand after roadway improvement and pricing policy implemented. In the Consensus transport model, where demand is changed due to changes in generalized cost and capacity levels, the formula of the index is given below in Equation 5 and then Equation 6 is used to forecast the new demand:

$$I = \left(\frac{CP_P}{CP_{BC}} \right)^{El._{CP}} \times \left(\frac{c_P^{m,tp,ut}}{c_{BC}^{m,tp,ut}} \right)^{El._c}$$

5.

$$Y_P^{m,tp,ut} = I \times Y_{BC}^{m,tp,ut}$$

6.

I : index ratio

CP_P : roadway capacity, for proposed project

CP_{BC} : roadway capacity, for base case

$c_P^{m,tp,ut}$: generalised cost of travelling by vehicle type (m), for trip purpose (tp), for user type (ut), for proposed project

$c_{BC}^{m,tp,ut}$: generalised cost of travelling by vehicle type (m), for trip purpose (tp), for user type (ut), for base case

$El._{CP}$: elasticity of demand with respect to roadway capacity

$El._c$: elasticity of demand with respect to generalized cost of travel

m : vehicle type, m= passenger car, truck

tp : trip purpose, tp = commuting, other

ut : user type, ut= frequent (discount), random

$Y_P^{m,tp,ut}$: demand by vehicle type (m), for trip purpose (tp), for user type (ut), for proposed project

$Y_{BC}^{m,tp,ut}$: demand by vehicle type (m), for trip purpose (tp), for user type (ut), for base case

Index and demand are estimated first by user type and trip purpose, then by vehicle type and finally they are aggregated. The basic result of equation 6 is forecasted demand in vehicle-kilometers travelled. Nonetheless, it can be transformed into traffic flow as well (in vehicles).

4.3 Computing stage

Third stage involves transferring conceptual process to computer code. The main product of this stage is a spreadsheet-based model, which can be used to produce estimates of traffic and related factors (speed, time and costs) changes per road pricing policy alternative examined. The (spread-sheet based) model is structured in two main interfaces: Input Data interface and Computational interface.

4.3.1 Input Data Interface

Input Data manipulation interface allows the user to: (i) describe current situation ("base-case") that generates the need of a specific road project, (ii) describe the proposed road project on which the various road pricing policy alternative scenarios will be tested, (iii) examine the available (pre-defined) set of alternative road pricing policy scenarios under comparison and (iv) enter readily available data concerning the “base-case” and/or proposed/alternative scenario; and –in the case of limited data availability- provide the user with a set of default data assisting him/her to make reasonable assumptions without much risk.

More specifically, “Input Data” worksheet contains separate sections for (manageable) data inputs:

(a) **General information**: Project Country, Project Name, Type of Project (Upgrade of existing roadway or New construction), Scale of Project (Corridor, Facility or Spot), Project Area (Urban/Small, Urban/Large or Interurban).

(b) **Base-case Roadway information**: Length (in km), Lanes/direction and Roadway Capacity/direction.

(c) **Project information**: Length (in km), Lanes/direction, Roadway Capacity/direction, Alternative options to the road user (availability of both routes and other modes, availability of other routes but no other modes, availability of other modes but not routes, no available routes or modes).

(d) **Base-case Traffic data information**: Average annual daily traffic in vehicles, Average annual kilometers travelled – and if not available- Average trip length, Peak hour factor, % of passenger cars in vehicle fleet, % of trucks in vehicle fleet, PCE (passenger car equivalent) of trucks, % of commuting trips, % of all other trip purposes, Speed for passenger cars, Speed for trucks.

(e) **Policy options to be examined**:

- Basic toll (else, the final toll level to be paid by a passenger car, in €/ in bound trip, regardless the pricing structure)
- Data concerning frequent (ETC) users (% of ETC users and % discounts for ETC users)

Other data points in this section are mostly pre-defined options provided to the user (just to view), including:

- Road pricing type,

- Toll collection technique,
- Operation authority,
- Toll unit
- Toll levels per vehicle category (passenger & truck)

Each of these data points/cells is highlighted with a specific colour in order to guide users which data to put, alter or not, choose from a list etc.

Values for the following key parameters for the base case scenario and the roadway improvement (proposed project) scenario should be estimated by users since they cannot be assumed or found –as default values- in any data sources:

- Project's country and name,
- Roadway length (in kilometres), both for base case and proposed project,
- Average Annual Daily Traffic, for base case,
- Share of commuting trips in total trips,
- Average travel speed for passenger cars,
- Average travel speed for trucks,
- Basic Toll,

All other values are either pre-defined drop-down lists, default values - based on recommended values in transport literature as well as current transport practice depicted from experts in road sector- or calculated values. Default values are further separated into two categories; those that can and those that cannot be altered.

Drop-down lists of values include, the following (lists of values include options in brackets -as formed based on current practice):

- Type of Project (Upgrade of existing roadway or New construction),
- Scale of Project (Corridor, Facility or Spot),
- Project Area (Urban/Small, Urban/Large or Interurban),
- Lanes/direction (1, 2, 3, 4, 5, 6),

- Alternative options offered to the road user (availability of both routes and other modes, availability of other routes but no other modes, availability of other modes but not routes, no available routes or modes),

Default values that can be altered are:

- Peak hour factor; suggested value –on EU level- is 8%,
- % of trucks in vehicle fleet; an average –on EU level- suggested value is 15%,
- Passenger Car Equivalent (PCE) of trucks; a value of 3.5 is used, based on common transport analysis practice in EU countries,
- ETC market penetration; values used in the model vary from 40% to 100%, according to the type of area as well as toll collection technique.
- % discount of ETC users; suggested values vary from 0% to 15%, according to toll collection technique.

  ETC related values were empirically suggested from road authorities' and operators' representatives, from EU countries, that participated in the two Consensus pilot trials.

Default values that cannot be altered include:

- Lane capacity (1800 PCE/hour for urban corridors; 2000 PCE/hour for interurban corridors) (TRB, 1994),
- Average trip length (for urban/small areas the suggested value is 10 km, for urban/large areas 15 km and for interurban areas 35 km) (CE Delft et. al, 2008),
- Road pricing type (pre-defined types, decided when setting the transport policy context of Consensus: flat-rate, distance-based or congestion charging),
- Toll collection technique (pre-defined techniques, decided when setting the transport policy context of Consensus: pass, toll booths, Electronic Toll Collection (ETC), Optical Vehicle Recognition System (OVR), GPS (or GNSS) based pricing and their combinations),
- Operation authority (public or private entity),
- Toll unit (€/in bound trip or €/km travelled, based on common transport analysis practice)

All other values are calculated, i.e. % of passenger cars in vehicle fleet is calculated subtracting the respective % of trucks.

After user provides all necessary input values, a range of alternative road pricing policy scenarios, which are applicable/suitable for the proposed project, is provided by the model in order to be tested next in the Computational interface.

These policy scenarios include all possible combinations of: road pricing policy types (flat-rate, distance-based or congestion charging), toll collection techniques (passes, toll booths, Electronic Toll Collection (ETC), Optical Vehicle Recognition System (OVR), GPS (or GNSS) based pricing - and their combinations), the authority responsible for road operation (public or private entity), the price level and possible variations (i.e. per vehicle category, per frequency of use/ETC users market penetration and discount of ETC users).

Model produces a unique ID for each policy scenario, in order to ease its identification from the user in one glance i.e. a road pricing policy scenario concerning application of flat-rate Road Toll on a roadway operated by a public authority, where car users pay 3€/in bound trip, either by stopping at toll booths or using ETC smart card, will have an ID of "**Road Tolls_Booths&ETC_3_€/in bound trip_Public**".

4.3.2 Computational interface

Based on data provided into the "Input Data" interface and using the algorithms and databases presented in the Conceptual Stage, traffic impacts (in terms of vehicle-kilometers travelled) of all the applicable road pricing policy scenarios (identified by their IDs) are estimated. No values within this worksheet should be altered by the user.

First, for each alternative road pricing policy scenario the model, based on the average daily traffic of base case, as specified by the user, and the average trip length (the selected default value is based on project's area, as defined by the user) calculates vehicle-kilometers travelled (VKT) in base case. Then, using VKT of base case, the initial daily and hourly VKT (using average days/ year and peak hour factor) per vehicle type and trip purpose (using fleet composition data as well as trip purposes data) are estimated.

Following that the Level-of-Service (LoS) of the base-case roadway is calculated based on the Highway Capacity Manual (HCM) method (TRB, 1994). According to the HCM, the LoS is based on the density of the vehicles, expressed in passenger cars per km per lane and is evaluated with average travel speeds (Table 2).

Table 2. HCM Level of Service Criteria, for basic freeway sections

LoS	**Description**	**Speed (km/h)**		**Flow (veh/h/lane)**	
A	Free flow; complete mobility	>=98		0	700
B	Reasonably free flow. Manoeuvrability is slightly restricted	92	97	701	1100
C	Stable flow. Ability to pass/change lanes constrained.	88	91	1101	1550
D	Approaching not stable flow. Speeds somewhat reduced, vehicle manoeuvrability limited.	75	87	1551	1850
E	Unstable flow. Flow becomes irregular, speed vary and rarely reach the posted limit. This is considered a system failure.	49	74	1851	2200
F	Forced or break-down flow. Flow is forced; travel time is unpredictable.	0	48	2201	3000

Next step is calculation of the generalised costs of travel for the base case (per vehicle type and trip purpose). This is done using equations 2 and 3 as well as VoT values (based on project's country, vehicle type and trip purpose), speed (based on vehicle type) and average trip length (based on project's area).

Then, investigation of how the additional capacity -in comparison to the base-case - will affect traffic flows and travel speed, takes place. This is estimated using the Index of capacity and the elasticity of demand (in VKM) with respect to capacity. This is done using equation 5. The additional capacity is estimated based on lanes per direction and lane's capacity (based on project's area).

Once vehicle travel speed of the built scenario is estimated (using HCM method) the generalised costs for all vehicle types and trip purposes are calculated, in each alternative road pricing policy scenario, using equations 2 and 3. Then the ratio of old over new generalised cost is calculated (Index), using the elasticity of demand with respect to generalised cost (using equation 5).

The final product is the computation of the final daily VKT per vehicle types for each of the alternative road pricing policy scenario examined, using equation 6.

4.4 Calibration/Validation Stages

In the absence of real traffic data, models can be calibrated by using default values derived from other studies. This is clearly the situation of Consensus transport model, as this model is a sketch elasticity-based one, developed for the generic case of a new or upgrade of an existing project, and as such: (a) there is no specific location and/or network simulated and (b) all parameters and equations are based on extended literature and practice review.

Based on this assumption, the model is by default calibrated, while validation can be performed by reviewing the performance of the model on a number of case studies and by comparing the estimated results with the expected values (traffic and related impacts) based on existing literature.

As this transport model is generally represented by one cordon link, it should be validated against Average Annual Daily Traffic (AADT) counts (for the base year), and observed average travel speed of a road project either concerning a sole road corridor or at least a very simple network.

The standard theory and method used to compare modelled values against observations on a link involves the calculation of the Geoff Havers (GEH) statistic, which is an empirical form of the Chi-squared statistic, proven extremely useful for a variety of traffic analysis.

The empirical formula for the "GEH Statistic" is:

$$GEH = \sqrt{\frac{2*(M-C)^2}{M+C}}$$

7.

where M is the average hourly traffic volume from the traffic model and C is the observed average hourly traffic count.

In general a GEH value of less than 5.0 is considered as a good match between the modelled and observed flows. A GEH value in the range of 5.0 to 10.0 may warrant further investigation, and a GEH value >10 means that there is some error either in the modelled volume or the observed volume at that particular location.

A number of tests, based on real/implemented case studies (provided by road authorities participated in the Consensus project pilots) were run using the transport model and all returned GEH values ranged between 3.5-4.7; these results indicated a rather good mach between modelled and observed flows.

5. Conclusions

The transport model described in this paper, was applied in the framework of Consensus project pilots' application in order to produce a (defensible) simulation of "immediate" (first-order) impacts of road pricing policies (traffic volume, amount of travel, journey time, speed etc.) on a given road project. Model results supported the estimation of the traffic-oriented/-related policy objectives of the Consensus transport policy scenario (i.e. reduction of traffic congestion, improvement of safety level, improvement of air quality and reduction of noise annoyance).

Consensus transport policy scenario final results were evaluated from all pilot users (in total 35) among others, in terms of "Reliability of results". The specific key Performance Indicator (KPI) meant to evaluate, among others, the ability of the transport model in producing (if not accurate at least) approximate, yet comparatively reliable, estimates of road pricing policies' impacts. Pilot evaluation results, for the specific KPI, verified that model's results seem rather realistic and the model was considered as able to supply an objective, scientifically supported 'first glance' of alternative road pricing policy options impacts and as such assist in their pre-screening of those promising for further development.

Analytical feedback, collected from interviews performed during pilot evaluation process indicated both pros and cons of the developed model.

Consensus model, as all simplified models has certain limitations and its results will always contain uncertainties, no matter how sophisticated this may become; it cannot represent a detailed network or spatial areas and since it relies on the transfer of assumed relationships from one context to another it is not suitable for detailed project appraisal. To this end, Consensus transport model, like all simplified sketch models, need to be used and interpreted appropriately and can only ever provide indicative, comparative and approximate answers.

On the other hand, Consensus transport model does not produce misleading results, order of magnitude type errors or incorrect relationships, any of which would be unhelpful or potentially counter-productive. It might not produce accurate results but it provides "*approximate, yet comparatively reliable, estimates*" (CONSENSUS, 2016). Furthermore, it is -by far- an easier/less complex, less time consuming, less data demanding and as such less expensive to use transport model. Finally, since it is structured for the "generic case" of a new road project or for the upgrade of an existing one it can be adapted to any road project, as long as this project concerns a sole road corridor or at least a very simple network.

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